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Mobile, Virtual Enhancements for Rehabilitation (MOVER)

Quarterly Progress Report

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INTRODUCTION AND EXECUTIVE SUMMARY

Research Goals

Injured Warfighters return home to face long-term care and recovery in addition to life adjustments. Rehabilitation services—such as interventions for traumatic brain injury (TBI)-induced motor limitations, broken bones, spinal cord injuries, chronic pain, and amputation—enable these Warfighters to adjust to new living constraints and conditions and, in many cases, return to full health. While these services are readily available in military treatment facilities (MTFs) and veterans' affairs medical centers (VAMCs), not all patients have the time or ability to receive prolonged inpatient rehabilitation interventions. Furthermore, lengthy inpatient treatments are costly to MTFs and VAMCs, reducing the overall number and types of services that these facilities can provide.

Home-based and outpatient rehabilitation interventions hold great potential to improve the rehabilitation of our Warfighters. These rehabilitation interventions enable patients to continue with their daily lives during rehabilitation. Patients can perform professional duties; be with family; and be social with friends around the schedule of their rehabilitation practice, and all of these functions enable patients to better adjust to life changes that follow injury. Home-based and outpatient rehabilitation interventions are accessible to a wide range of patients because they lower the time and travel requirements of rehabilitation. Finally, home-based and outpatient rehabilitation interventions are less costly to MTF and VAMC service providers, enabling these facilities to provide a wider range of services to more patients.

The patient must practice therapeutic exercises regularly. The unfortunate reality of many home-based and outpatient therapies is that the patient does not regularly practice therapeutic exercises beyond visits with the therapist and, therefore, does not see significant improvement. Studies of home-based and outpatient rehabilitation interventions have identified a number of key correlates to lack of adherence: confusion about exercises; perceptions of lack of time to exercise; forgetting to exercise; perceptions of helplessness; and overall lack of motivation to exercise (Jette et al., 1998; Sluijs, Kok, & van der Zee, 1993). Conversely, patients who have less confusion, make time to exercise, remember to exercise, perceive higher self-efficacy, and report motivation to exercise adhere more regularly to rehabilitation protocols. In addition to these areas of needed patient assistance, outpatient therapists must be enabled to perform their job functions of observing the patient and directing exercises.

For these reasons, remote assistance to home-based and outpatient rehabilitation is needed to enhance the recovery of our injured Warfighters.

Description of the Technical Approach

To address these issues, we are developing mobile, virtual enhancements for rehabilitation (MOVER), a mobile, technology-enabled home-based rehabilitation intervention delivery system. MOVER features (1) a mobile application to provide education, information, and scheduling of therapeutic exercises; (2) virtual coaches to guide, mentor, and motivate patients; (3) COTS input devices and video games to increase patient motivation; and (4) a web-based therapist interface to accurately assess patient adherence and progress.

Figure 1 shows the MOVER Architecture. At the top left of the figure, the **Patient** interacts with the **MOVER Mobile Application** to perform **Exercise Scheduling** and obtain **Information and Education** about therapeutic exercises. The **Virtual Coaches** exist on the mobile application and provide interactive guidance and mentoring about the rehabilitation process and therapeutic exercises. When the scheduled time for the exercises arrives, the mobile application reminds the patient, and the patient begins an exercise session with the **MOVER Game Integration**, as shown at the bottom of the figure. The patient uses **COTS input devices**, such as the Microsoft Kinect and the Wii Balance Board, to perform therapeutic exercises that are mapped to controls of the **Video Game Console** through the **Control Mapping on Laptop,** software running on an inexpensive PC or laptop.

During interaction with the mobile application and game integration, patient **Performance** is recorded and sent securely to the **Remote Server** and **Secure Database**, at the center of the figure. The **Therapist** reviews this performance through summarized **Progress Reports** in the web-based **Therapist Interface**, as shown at the top right of the figure. The therapist then creates **Therapeutic Exercise Assignments** to describe the patient's therapeutic exercises for the next week, and these assignments are passed to the game integration for implementation the next time the patient begins exercise.

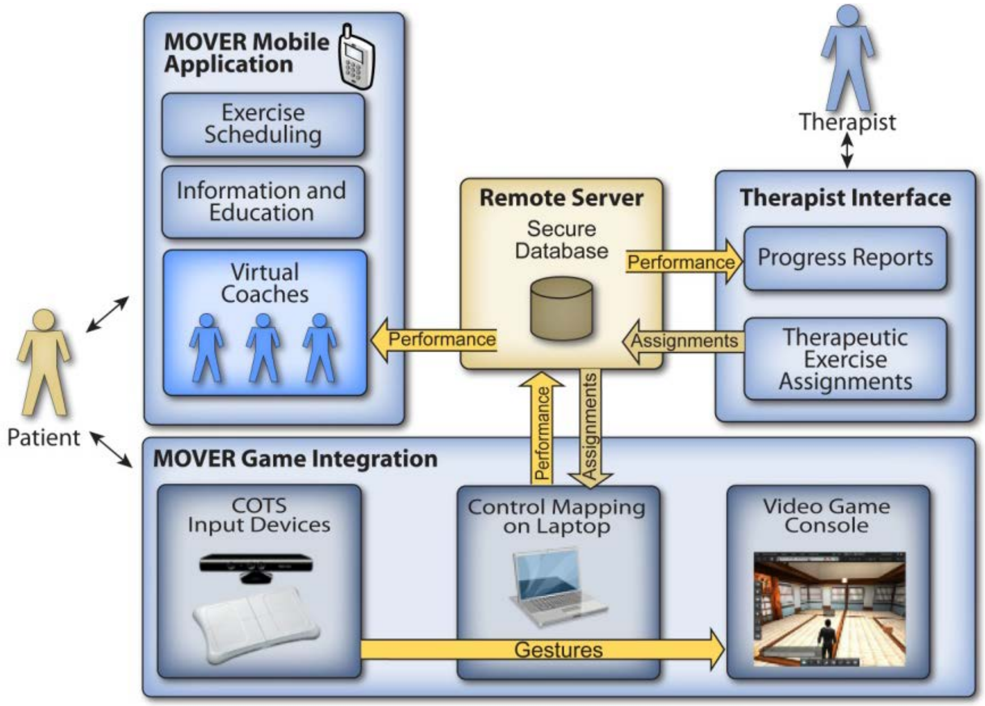

Figure 1: MOVER architecture

A typical use of MOVER in home-based rehabilitation is as follows. The patient meets with the therapist at the beginning of the week to participate in a short, one-on-one rehabilitation session. The therapist assesses the patient, prescribes a set of therapeutic exercises for the week, and works with the patient to determine a feasible exercise schedule. At the end of the session, the patient and therapist enter an exercise schedule for the week, and the therapist enters the therapeutic exercises into the therapist interface. During the week, the patient is reminded of scheduled exercises by the mobile application and motivated by the virtual coaches. The patient uses the COTS input devices to play the video games with the therapeutic movements specified by the therapist. During exercise, the virtual coaches give feedback on patient movements and form, and afterwards the virtual coaches review the patient performance. Performance information is collected and sent to the remote server. At the next session, the therapist reviews the progress reports with the patient to determine next steps for treatment.

Deliverables/Milestones Schedule

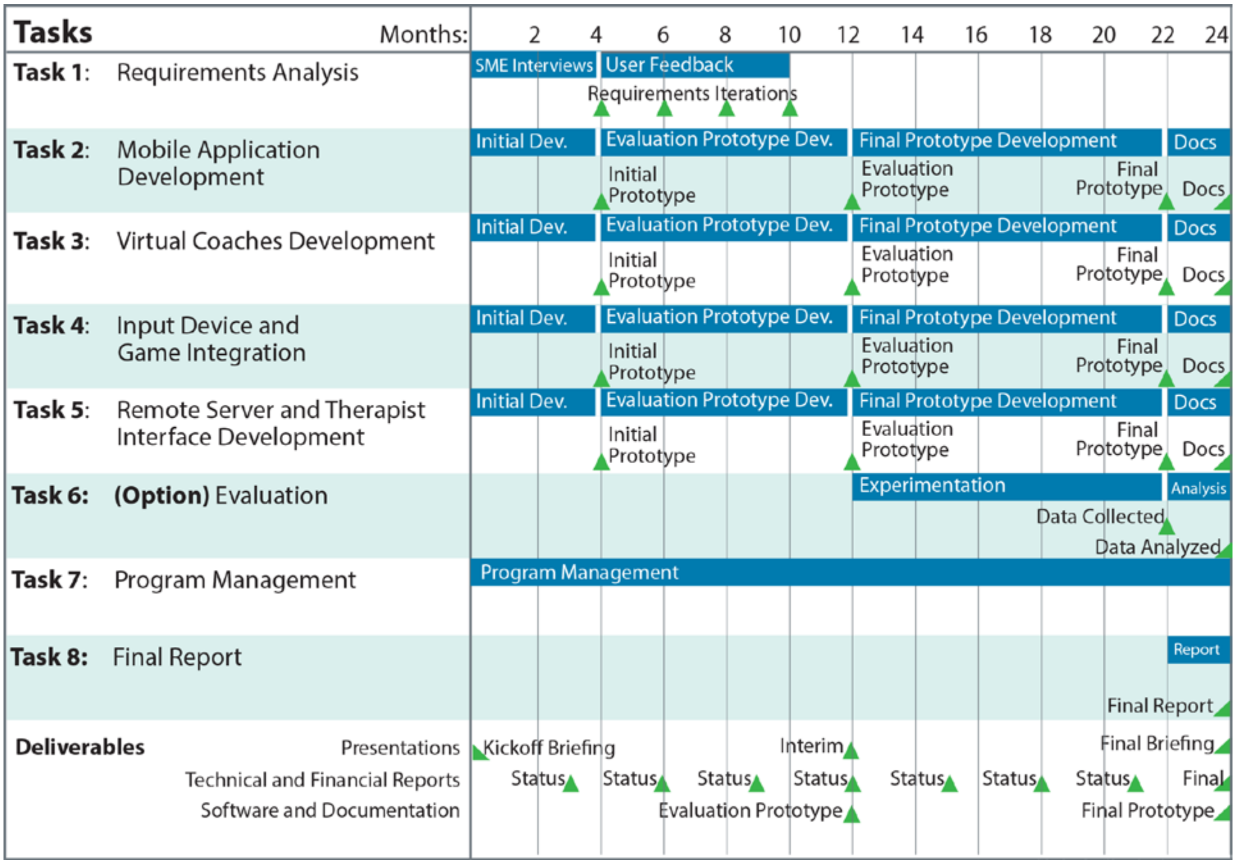

Figure 2: MOVER deliverables and milestones schedule

TECHNICAL PROGRESS

Progress against Planned Objectives

During the current reporting period, we began our initial requirements analysis and development as per the schedule in Figure 2.

Technical Accomplishments This Period

During this reporting period, we focused on Task 1 (Requirements Analysis), Task 2 (Mobile Application Development), Task 3 (Virtual Coaches Development), Task 4 (Input Device and Game Integration), and Task 7(Program Management) as presented in the Statement of Work for this effort.

Task 1: Requirements Analysis

Our goal for Task 1 is to conduct knowledge elicitation with TBI motor impairment therapists and patients, identify needed extensions to existing treatments, and create a requirements specification for this system.

During the current reporting period, we (1) began our discussions with TBI-induced mobility limitation subject matter experts (SMEs), including both therapists and researchers who interact with this patient population (2)

developed user personas to represent potential users of the system and (3) clarified initial requirements of the system.

Through SME discussions, we identified additional context for the use of the system. Once MOVER is fully developed, we envision that patients will be interacting with the games in an outpatient or self-directed setting within the clinic (e.g., have the system available in their inpatient room). Because this population may have balance control issues that may lead to falls or injuries, patients must be carefully screened in these cases to determine the safety of playing the games unsupervised. Also, some exercises may be performed from non-standing positions, greatly reducing the likelihood of injuries. These include both seated exercises for vestibular problems that may lead to gaze instability and general strengthening and conditioning exercises such as lying down leg and upper extremity exercises. We may use these limitations as criteria for our evaluation study (under the Task 6 Option), though we plan to supervise participants closely during this stage of development. One of the objectives of the evaluation will be to determine which populations may safely use MOVER unsupervised.

We have tentatively set the date of January 14th 2014, as our next on-site visit at Spaulding Rehabilitation Hospital. At this meeting we will hold knowledge elicitation with our therapist SMEs in the morning and observe patient therapy sessions in the afternoon. We will finalize this date once we receive final approval from Spaulding management for the patient observations and therapist schedules are set for the new year.

To better meet the needs of our users, we have developed several user personas that represent the needs and variations of potential users of the system. Grudin and Pruitt (2002) note about persona design: “Not only can it be a powerful tool for true participation in design, it also forces designers to consider social and political aspects of design that otherwise often go unexamined.” The personas we have developed to date include 3 patients, 2 therapists, a therapist group leader, and a hospital information technology (IT) administrator. Through this process we identified several key variants in patients, including:

- Condition and physical capability
- Technical savviness
- Video game experience and preferences
- Other TBI symptoms
- Comorbid health and mental health issues to TBI (e.g., PTSD)
- Attitude toward treatment
- First language and general reading ability
- Ability to attend therapy
- Drive and determination to improve abilities

We also identified key variants in therapists and staff:

- Job experience
- Knowledge of TBI and related therapies
- Experience with inpatient and outpatient settings
- Emotional support
- Technical savviness
- Willingness to try new therapies
- Cost concerns

In addition to our design and SME interactions, we attended the Artificial Intelligence and Interactive Digital Entertainment (AIIDE) 2013 conference in Boston, MA to stay abreast of the latest developments in this research area and make key contacts for future MOVER development. AIIDE is focused on the latest advances in AI as they relate to interactive digital experiences, and it is therefore highly related to the goals of MOVER. In addition to numerous interactions with university and private sector researchers in this area, many of the conference papers and talks were informative for MOVER development, especially for the virtual coaches and COTS games use. Below are brief summaries of three of these relevant papers and talks.

Sara Bernardini, Kaska Porayska-Pomsta, Harini Sampath, Designing an Intelligent Virtual Agent for Social Communication in Autism, AIIDE, Boston, MA. 2013.

From the abstract: “This paper describes the Intelligent Engine (IE) of ECHOES, a serious game built for helping young children with Autism Spectrum Conditions acquire social communication skills. ECHOES IE’s main component is an autonomous virtual agent that acts as a credible social partner for children with autism by engaging them in interactive learning activities.”

This virtual agent is based on previous work in the FAtiMA agent architecture (Dias and Paiva 2005; Aylett, Dias, and Paiva 2006). FAtiMA agents use a theory of emotions and appraisal theory to interpret events and generate expressive behavior. These agents appraise the environment around them through scripted rules and then cope with the environment and their internal emotions using either problem-focused (e.g., problem solving) or emotion-focused (e.g., expression or re-interpretation) strategies. These agents have been shown to be engaging for straightforward tasks that involve an emotional component. With the MOVER virtual coaches, these strategies of appraisal and coping can be incorporated to provide more authentic and engaging interaction.

Andrew Kope, Caroline Rose, Michael Katchabaw, Modeling Autobiographical Memory for Believable Agents, AIIDE, Boston, MA. 2013.

From the abstract: “We present a multi-layer hierarchical connectionist network model for simulating human autobiographical memory in believable agents. Grounded in psychological theory, this model improves on previous attempts to model agents’ event knowledge by providing a more dynamic and nondeterministic representation of autobiographical memories.”

This paper models memory of world events and objects in virtual agents by an ACT-R style connectionist network. This network enables the virtual characters to recall experiences and associations in a more naturalistic and believable manner. For the MOVER virtual coaches, the recall of specific interactions with a patient and natural associations between these interactions can be a useful tool for building history and rapport with the patient, as well as motivating exercises. The basic assumption is that if the coach exhibits memories of interactions, these interactions become more meaningful and the patient will treat them with more care.

Daniel Shapiro, Josh McCoy, April Grow, Ben Samuel, Andrew Stern, Reid Swanson, Mike Treanor, Michael Mateas, Creating Playable Social Experiences through Whole-Body Interaction with Virtual Characters, AIIDE, Boston, MA. 2013.

From the abstract: “This paper describes work towards the goal of enabling unscripted interaction with non-player characters in virtual environments. We hypothesize that we can define a layer of social affordances, based on physical and non-verbal signals exchanged between individuals and groups, which can be reused across games.”

This paper presents emerging work combining previous work on social simulations with gestures and whole-body interactions, enabling virtual agents to be socially aware of their own and the player’s non-verbal signals. The MOVER system has the ability to track patient movements and may be able to discern key social indicators that could inform interaction with the system. Also, the body language and social cues of the virtual coaches are a powerful feedback channel and motivator for the patient which may be used via models of non-verbal communication such as the one described in this paper.

Task 2: Mobile Application Development

Our goal for Task 2 is to develop a mobile application to accompany home-based TBI motor impairment rehabilitation therapy. We will also enhance therapy protocols to use the mobile application and develop methods to enable therapist and peer support through the mobile application.

During the current reporting period, we investigated the use of our current iOS-based application framework for developing the MOVER mobile application (app). The framework is flexible and highly usable for developing apps that consist largely of static screens with input forms and multimedia such as pictures, sounds, and videos. It

supports sending, storing, and receiving data securely with a remote server, which MOVER may use to provide a therapist portal. Because of these features and our existing expertise in this framework, it will be a strong platform to begin our development. The to-be-defined requirements of the virtual coaches my necessitate expanding this framework to include technologies that allow for real-time animation and interaction with virtual characters. Possibilities for these capabilities largely include game engines such as Microsoft's XNA framework or the Unity 3D platform.

Task 3: Virtual Coaches Development

Our goal for Task 3 is to develop virtual coaches to assist home-based TBI motor impairment rehabilitation therapy through mentoring and guidance. The virtual coaches development is awaiting finalization of the virtual coaches requirements. The virtual coaches are one of the most flexible components of the MOVER system and will be highly tailored to the needs of the end users.

Task 4: Input Device and Game Integration

Our goal for Task 4 is to integrate commercial-off-the-shelf (COTS) input devices and COTS video games to engage the patient and estimate body posture during therapeutic exercises.

During the current reporting period, we investigated potential input devices. Patients interact with the video games through COTS movement-based input devices, such as the Microsoft Kinect or Nintendo Wii Balance Board. The input devices are connected to a computer laptop running MOVER gesture recognition algorithms that remap patient movements to game controls that are sent to the video game console. The current generation Kinect has several APIs and open toolkits available, including the official Microsoft SDK. We have integrated with these APIs under previous efforts, as shown in Figure 3. Microsoft has announced the next generation of the Kinect sensor will include higher definition video, 3D, and audio tracking, scheduled for release in summer of 2014. The additional resolution and tracking capability of this new sensor would be extremely beneficial to MOVER as it monitors patient movements during exercise. We will continue to follow this progress and investigate early developer programs to move towards obtain this technology.

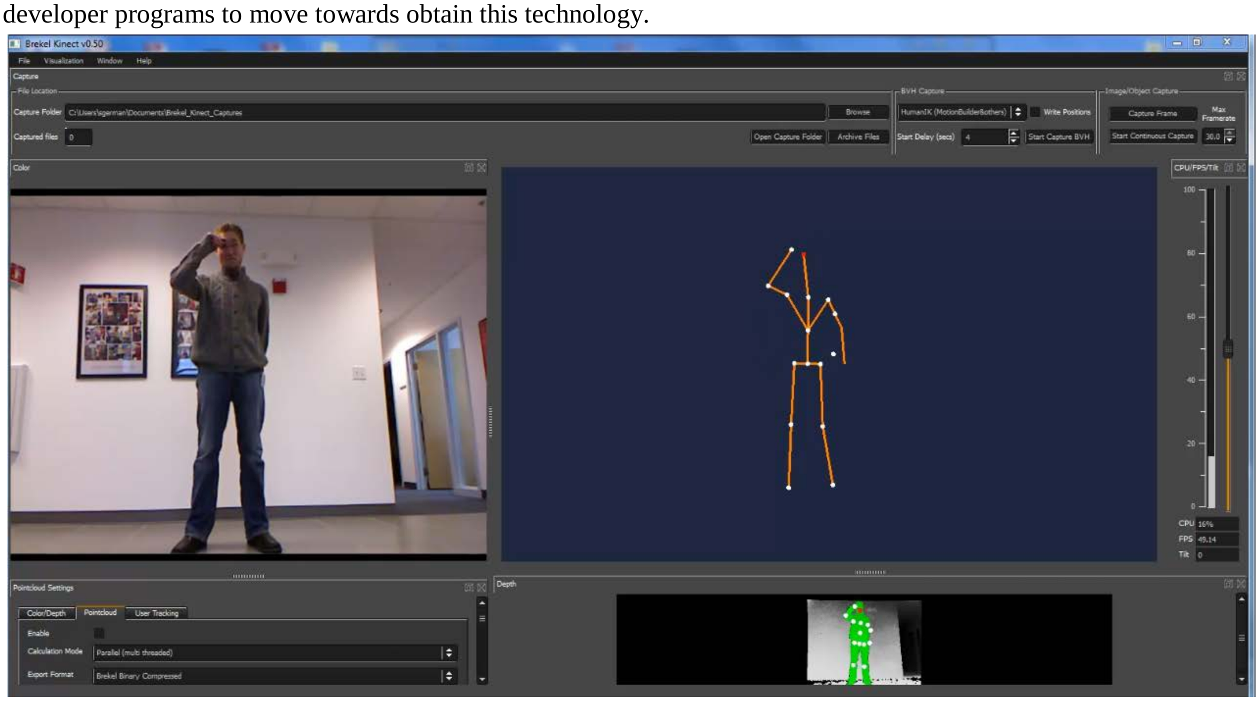

Figure 3: Microsoft Kinect input creating a 3D representation of user poses

In addition to the Kinect sensor, the Nintendo Wii balance board and the new Sony Playstation 4 Eye camera offer potential alternatives to monitor patient movement. Specific tradeoffs between these devices include range and

type of detectable motion, accuracy, and cost. We will make this determination for our initial MOVER prototype as we finalize our system requirements, while maintaining the possibility for rapidly including new and additional input devices through well-defined APIs.

Task 7: Program Management

Our goal for Task 7 is to coordinate team activities, author status reports, and brief the Sponsor on project progress as appropriate.

During the current reporting period, we held the kickoff briefing for MOVER at ONR offices with LCDR Brent Olde and Dr. Paul Chatelier.

We have executed the subcontract agreement and Spaulding Rehabilitation Hospital is now under contract for MOVER. We also finalized and received approval for our evaluation from the Spaulding Rehabilitation Hospital IRB.

Significant Changes to Technical Approach to Date

At the time of writing, no significant changes have been made to the MOVER technical approach.

Deliverables Submitted This Period

No deliverables were submitted this reporting period.

Milestones Reached/Achieved During This Period

No milestones were scheduled for this reporting period.

PROJECT PLANS

Specific Objectives for Next Period

- During the next time period, we plan to focus on Task 1 (Requirements Analysis),Task 2 (Mobile Application Development), Task 3 (Virtual Coaches Development), Task 4 (Input Device and Game Integration), Task 5 (Remote Server and Therapist Interface Development), and Task 7(Program Management).
- Under Task 1 we will conduct knowledge elicitation sessions with our SMEs, observe patient therapy, and develop an initial draft of the complete requirements for the system.
- Under Task 2, we will continue to design the MOVER mobile application and identify needed extensions to our existing in-house mobile application framework.
- Under Task 3, we will begin significant design of the virtual coaches.
- Under Task 4, we will continue to investigate potential input devices and begin integration with the Microsoft Kinect.
- Under Task 5, we will begin design and development of the remote server and therapist interface.

ISSUES OR CONCERNS

During this reporting period, we encountered an issue with potential funding of the MOVER Option (Task 6 in the Statement of Work). The MOVER Option contains primary evaluation task with patients. To address this issue, we will continue to develop the system with input from subject matter experts. We will continue to seek possibilities for funding the option and explore follow-on efforts for clinical evaluation.

We do not foresee any other potential issues at this time.

EXPENDITURES

Total Contract Amount	$767,388.00
Costs Incurred this reporting period	$39,933.00
Costs Incurred to Date	$39,933.00
Estimated % to completion	5%